Atomic Energy Control Board
P.O. Box 1046
Ottawa, Canada
K1P 5S9

Commission de contrôle de l'énergie atomique
C.P. 1046
Ottawa, Canada
K1P 5S9

INFO-0369

DETERMINATION OF ANNUAL LIMIT ON INTAKE FOR LONG-LIVED RADIOACTIVE DUST

by

S.H. Ching and F.J. Horvath
Atomic Energy Control Board

August 1989

Canada

Paper

DETERMINATION OF ANNUAL LIMIT ON INTAKE FOR LONG-LIVED RADIOACTIVE

ABSTRACT

A method for the determination of the annual limit on intake (ALI) for long-lived radioactive dust (LLRD) that is associated with every step in the uranium production process is proposed. It is based on methodology indicated in ICRP 26. A sample calculation for the ALI of fresh yellowcake is provided in Appendix A to assist in explaining this method.

RÉSUMÉ

On propose une méthode pour déterminer la limite annuelle d'incorporation (LAI) des poussières radioactives à période longue, qui sont présentes à chaque étape de la production de l'uranium. Cette méthode, basée sur la méthodologie indiquée dans la publication CIPR 26, est illustrée à l'annexe A du présent document par un exemple de calcul de la LAI pour du concentré d'uranium frais.

TABLE OF CONTENTS

ABSTRACT i

A. INTRODUCTION 1

B. OBJECTIVE 1

C. PROCEDURE: Method for Calculating ALI for LLRD 2

References 6

Appendix A: Determination of ALI for LLRD in Yellowcake Area of the Milling Process 7

A. INTRODUCTION

In certain sectors of the nuclear fuel cycle, workers are exposed to mixtures of radionuclides in co-existence with their respective decay daughter products at different degrees of secular equilibrium. For example, some uranium miners are exposed to radon, thoron, and their respective daughter products, as well as airborne long-lived radioactive dust (LLRD). In underground mines, open pit operations, and at the front end of the uranium milling cycle, airborne LLRD particles contain all the radionuclides that are present in the ore. In the yellowcake areas of the mills and refineries, LLRD particles contain mostly uranium isotopes.

The individual annual limit on intake (ALI) for most radionuclides can be obtained from ICRP publication 30[1] with the ALIs for radon and thoron daughters available in ICRP 32[2]. However, since LLRD contains mixtures of radionuclides which are in different proportions (because of differing degrees of equilibrium) and are attached to airborne particulates of different sizes, the calculation of ALIs for LLRD is not a straightforward matter. In addition, ALIs for some radionuclides are derived from the stochastic dose limit, while others are derived from the non-stochastic dose limit, depending upon which limit is more restrictive.

B. OBJECTIVE

The objective of this guide is to provide licensees with a method which is acceptable to the Atomic Energy Control Board for calculation of ALIs for LLRD; it does not provide guidance for specific operations. However, to assist in explaining this method, a sample calculation for the ALI of fresh yellowcake is provided in Appendix A.

C. PROCEDURE: Method for Calculating ALI for LLRD:

1) Prerequisite:

In order to calculate the ALI for LLRD, the following physical parameters must be determined or estimated:

a) Activity Median Aerodynamic Diameter (AMAD);

b) radionuclides present in the LLRD;

c) percentage contribution of each radionuclide to the total activity of the LLRD; and

d) solubility class of each radionuclide in the LLRD.

2) Calculation of ALI for LLRD:

2.1) Since LLRD is a mixture of different radionculides, the equation for determining the ALI for a mixture[3] is:

$$\frac{1}{\underset{\text{(stochastic)}}{\text{ALI (LLRD)}}} = \sum_{i=1}^{n} \frac{k_i}{\underset{\text{(stochastic)}}{\text{ALI}_i}} \qquad \text{(1a)}$$

or

$$\frac{1}{\underset{\text{(non-stochastic)}}{\text{ALI (LLRD)}}} = \sum_{i=1}^{n} \frac{k_i}{\underset{\text{(non-stochastic)}}{\text{ALI}_{i,T}}} \qquad \text{(1b)}$$

where, ALI_i is the stochastic annual limit on intake for the ith radionuclide of the mixture, $ALI_{i,T}$ is the non-stochastic annual limit on intake for the ith radionuclide for target organ T, and k_i is the fraction of the activity of the dust due to the presence of the ith radionuclide.

And,

$$ALI_i \text{ (stochastic)} = \frac{0.05 \text{ Sv}}{\Sigma_T \, w_T \cdot (H^i_{50,T} \text{ per unit intake})} \qquad (2)$$

$$ALI_{i,T} \text{ (non-stochastic)} = \frac{0.5 \text{ Sv}}{H^i_{50,T} \text{ per unit intake}} \qquad (3)$$

where, w_T is the weighting factor for target organ T and $H^i_{50,T}$ is the 50 year committed dose equivalent to target organ T per unit intake of radionuclide i.

The ALI_i and $ALI_{i,T}$ values used are calculated from the $H^i_{50,T}$ for each significantly irradiated organ or tissue per unit intake, given in the ICRP 30 Publications and Supplements for the relevant radionuclides.

Equations (1a) and (1b) are used to calculate the ALI of the mixture based on the ALI values of individual nuclides, some of which limit the occurrence of stochastically-produced detriment while others are based on the prevention of non-stochastic effects of radiation dose.

The applicable ALI is usually the smaller of (1a) and (1b). In practice, however, the ALI based on the stochastic limit should be used when doses from other sources, such as external gamma radiation and radon and thoron daughters, are to be combined to calculate total effective doses.

2.2) Equations (2) and (3) cannot be solved without first considering the effect of particle size on the calculation of ALI_i and $ALI_{i,T}$.

The ALI_i for individual radionuclides calculated from equations 2 and 3 or given in ICRP 30 assume an AMAD of 1 μm. Values for $H_{50,T}$ for different particle sizes are calculated with the following equation:

$$H_{50,T}\,(\text{AMAD}) = \sum \left[f_{N\text{-}P} \cdot \frac{D_{N\text{-}P}\,(\text{AMAD})}{D_{N\text{-}P}\,(1\ \mu\text{m})}\,i + f_{T\text{-}B} \cdot \frac{D_{T\text{-}B}\,(\text{AMAD})}{D_{T\text{-}B}\,(1\ \mu\text{m})}\,i + f_P \cdot \frac{D_P\,(\text{AMAD})}{D_P\,(1\ \mu\text{m})}\,i \right] \cdot H_{50,T}\,(1\ \mu\text{m}) \qquad (4)$$

where, $f_{N\text{-}P}$, $f_{T\text{-}B}$ and f_P are the fractions of the committed dose equivalent in the reference tissue resulting from radionuclide deposition in the naso-pharynx (N-P), tracheo-bronchial (T-B), and pulmonary (P) regions of the respiratory system respectively; $D_{N\text{-}P}$ (AMAD), $D_{T\text{-}B}$ (AMAD), D_P (AMAD) are the deposition probabilities in the respiratory regions for dust particles of a given AMAD; and $D_{N\text{-}P}$ (1 μm), $D_{T\text{-}B}$ (1 μm), D_P (1 μm) are the deposition probabilities of particles of 1 micrometre AMAD in the corresponding regions of the respiratory tract.

It should be noted that $f_{N\text{-}P}$, $f_{T\text{-}B}$ and f_P in equation (4) are functions of the target organ and the inhalation class (D, W, Y) of the radionuclide. These numbers can be obtained from ANNALS of ICRP, ICRP 30, supplement to Part 1, Volume 3, No. 1-4.

It should also be noted that the ICRP does not assign an $H_{50,T}$ (1 μm) for each radionuclide in each inhalation class. However, for radionuclides for which ICRP 30 provides data for class W compounds but not for class Y, $H_{50,T}$ for the lung for class Y may be approximated by:

$$H_{50,T}^{i}(1, \text{class W}) = \frac{1}{20} H_{50,T}^{i}(1, \text{class Y}) \qquad (5)$$

where $H_{50,T}^{i}(1, \text{class W})$ is assigned by the ICRP for organ T, where T is the lung.

The factor 20 is derived as follows: a factor of 10 to account for the difference in the retention times of class Y and class W radionuclides in the lung times a factor of 2 to account for the difference in the retention of dust in the lymph nodes. It must be noted that equation (5) is only applicable to the lung, and not for other tissues or organs.

2.3) ALI_i (stochastic) and $ALI_{i,T}$ (non-stochastic) values can be obtained using equations (2) and (3). Equations (1a) and (1b) are then solved. The ALI (LLRD) chosen is the smaller of equation (1a) and (1b), depending on whether stochastic or non-stochastic effects are limiting. The ALI (LLRD) so calculated refers to the total activity, in becquerels, of the mixture, and not to the activity of any single constituent radionuclide.

References:

1. ICRP, Limits for Intakes of Radionuclides by Workers, Oxford, Pergamon Press, ICRP Publication 30, Part 1 and Supplements to Part 1, (1979).

2. ICRP, Limits for Inhalation of Radon Daughters by Workers, Oxford, Pergamon Press, ICRP Publication 32, (1981).

3. ICRP, Radiation Protection in Uranium and Other Mines, Oxford, Pergamon Press, ICRP Publication 24, (1977).

4. AECB INF0-0167-1, "Determination of the Contribution of Long-Lived Dust to the Committed Dose Equivalent Received by Uranium Mine and Mill Workers in the Elliot Lake Area, Volume I, P. Duport and E. Edwardson, November 1985.

5. AECB INF0-0167-2, "Determination of the Contribution of Long-Lived Dust to the Committed Dose Equivalent Received by Uranium Mine and Mill Workers in the Elliot Lake Area, Volume 2, Appendices by P. Duport and E. Edwardson, November 1985.

Appendix A

Determination of ALI for LLRD in Yellowcake Area of the Milling Process[4][5]

1. Assumed and Known Parameters:

   a) average activity median aerodynamic diameter (AMAD) for yellowcake = 5 micrometers

   b) fresh yellowcake:

      Only U-238 and U-234 and some impurities are present in fresh yellowcake and the activity of U-238 is equal to the activity of U-234. (The activity of U-235 is about 2% of that of U-234 and U-238 combined and, consistent with the "≥10%" rule of Part 1 of ICRP 30, is not included here). Therefore,

      k_i for U-238 = fraction of alpha activity of yellowcake = 0.5 = k_i for U-234

   c) solubility classes of uranium in typical fresh yellowcake:

      92% class D
      8% class Y
      (solubility of typical fresh yellowcake)

2. Calculation of H_{50} using Equation 4:

   For solubility class D, $H_{50,T}$ for U-234 with AMAD of 1 μm is 7×10^{-7} Bq for target tissue bone marrow.

Therefore, $H_{50,T}$ U-234 with an AMAD of 5 μm can be determined by equation 4:

$$\frac{H_{50}\text{ (U-234 for AMAD of 5 μm)}}{7 \times 10^{-7}}$$

$$= f_{N\text{-}P} \cdot \frac{D_{N\text{-}P}\text{ (5 μm)}}{D_{N\text{-}P}\text{ (1 μm)}} + f_{T\text{-}B} \cdot \frac{D_{T\text{-}B}\text{ (5 μm)}}{D_{T\text{-}B}\text{ (1 μm)}} + f_P \cdot \frac{D_P\text{ (5 μm)}}{D_P\text{ (1 μm)}} \qquad \text{(equation 4)}$$

where, for U-234 and target tissue red bone marrow:

$f_{N\text{-}P} = 0.33$ from p. 364 of ANNALS of ICRP, ICRP30,

$f_{T\text{-}B} = 0.16$ Supplement to Part I on the section for H_{50}

$f_P = 0.51$ of U-234

$D_{N\text{-}P}$ (5 μm) = 0.75

$D_{T\text{-}B}$ (5 μm) = 0.07

D_P (5 μm) = 0.08

- from ICRP 30, figure 5.2

$D_{N\text{-}P}$ (1 μm) = 0.30

$D_{T\text{-}P}$ (1 μm) = 0.08

D_P (1 μm) = 0.25

therefore, H_{50} (U-234 for AMAD of 5 μm with target tissue red bone marrow)

$= 7 \times 10^{-7}$ X 1.1

$= 7.7 \times 10^{-7}$ Sv/Bq

Similar calculations of H_{50} for other target tissues are listed in Table I for reference.

Committed effective dose equivalent for the same tissue can be obtained by multiplying the H_{50} with the respective weighting factor W_T.

e.g. $W_T H_{50}$ for red bone marrow is

$7.7 \times 10^{-7} \times 0.12 = 9.24 \times 10^{-8}$ Sv/Bq

The H_{50} and $W_T H_{50}$ for different tissues and different solubility classes are listed in Table I as well.

3) Calculation of ALIs for U-234 and U-238:

3.1) Calculation of non-stochastic ALI (U-234):

For class D: (See Table I)

The limiting target is bone surface with H_{50} of 1.21×10^{-5} Sv/Bq. Therefore, the non-stochastic ALI (U-234)

$$= \frac{0.5 \text{ Sv}}{1.21 \times 10^{-5} \text{ Sv/Bq}}$$

$$= 4.13 \times 10^{4} \text{ Bq}$$

3.2) Calculation of stochastic ALI (U-234):

For class D: (See Table I)

$\Sigma W_T H_{50} = 7.74 \times 10^{-7}$ Sv/Bq

therefore, stochastic ALI(U-234) $= \dfrac{0.05 \text{ Sv}}{7.74 \times 10^{-7} \text{ Sv/Bq}}$

$= 6.46 \times 10^4$ Bq

3.3) Calculations of ALI taking into consideration solubility classes:

e.g., non-stochastic ALI for U-234 for solubility classes 8% W and 92% D (See Table I)

using equation l(b)

$$\frac{1}{\text{ALI (U-234)}} = \frac{0.92}{4.13 \times 10^4} + \frac{0.08}{9.77 \times 10^4}$$

Therefore, the non-stochastic ALI for U-234 is 4.43×10^4 Bq.

Similar calculations are completed for stochastic ALIs for U-234 and ALls for U-238.

TABLE I

U-234 with AMAD of 5 μm

	$H_{50,T}$ (Sv/Bq) Class		$W_T H_{50}$ (Sv/Bq) Class	
Target Tissue	D	W	D	W
Red Bone Marrow	7.7×10^{-7}	-	9.24×10^{-8}	-
Lung	1.25×10^{-7}	5.12×10^{-6}	1.48×10^{-8}	6.14×10^{-7}
Bone Surface	1.21×10^{-5}	-	3.63×10^{-7}	-
Kidney	5.0×10^{-6}	-	2.97×10^{-7}	-
			$\Sigma W_T H_{50}$ $= 7.74 \times 10^{-7}$	$\Sigma W_T H_{50}$ $= 6.14 \times 10^{-7}$
ALI (non-stochastic)	4.13×10^{4}	9.77×10^{4}		
ALI (stochastic)			6.46×10^{4}	8.14×10^{4}

ALI (non-stochastic) for 8% W and 92% D = 4.43×10^{4} Bq

ALI (stochastic) for 8% W and 92% D = 6.57×10^{4}

TABLE II

U-238 with AMAD of 5 μm

Target Tissue	$H_{50,T}$ (Sv/Bq) Class D	$H_{50,T}$ (Sv/Bq) Class W	$W_T H_{50,T}$ (Sv/Bq) Class D	$W_T H_{50,T}$ (Sv/Bq) Class W
Red Bone Marrow	7.3×10^{-7}	-	8.7×10^{-8}	-
Lune	1.1×10^{-7}	4.48×10^{-6}	3.7×10^{-8}	5.37×10^{-7}
Bone Surface	1.1×10^{-5}	-	3.2×10^{-7}	-
Kidney	4.4×10^{-6}	-	2.6×10^{-7}	-
			$\Sigma W_T H_{50} = 7.0 \times 10^{-7}$	$\Sigma W_T H_{50} = 5.37 \times 10^{-7}$
ALI (non-stochastic)	4.5×10^{4}	1.12×10^{5}		
ALI (stochastic)			7.1×10^{4}	9.30×10^{4}

ALI (non-stochastic) for 8% W and 92% D = 4.73×10^{4} Bq

ALI (stochastic) for 8% W and 92% D = 7.23×10^{4}

4) Calculation of ALIs for Yellowcake with 92% class D and 8% class W:

4.1) Non-stochastic ALIs:

$$\frac{1}{ALI_{(NS)}} = 0.5\left[\frac{1}{4.43 \times 10^4} + \frac{1}{4.73 \times 10^4}\right]$$

therefore, $ALI_{(NS)} = 4.58 \times 10^4$ Bq.

4.2) Stochastic ALIs:

$$\frac{1}{ALI_{(S)}} = 0.5\left[\frac{1}{6.57 \times 10^4} + \frac{1}{7.23 \times 10^4}\right]$$

therefore, $ALI_{(s)} = 6.88 \times 10^4$ Bq.

4.3) ALI for fresh yellowcake:

$= 4.58 \text{ X } 10^4$ Bq of α activity

because the non-stochastic effects are the more limiting.